Transparent and Inclusive Land Expropriation through Geospatial Innovation

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Key words: Expropriation, Geospatial Technologies, Remote Sensing, UAV Mapping, LiDAR.

SUMMARY

Rapid urbanization increases the demand for housing, infrastructure, and public services, creating challenges for fair, transparent, and efficient land acquisition. Traditional expropriation methods, based on field surveys, manual boundary verification, and committee-led valuations, are time-consuming, labor-intensive, and prone to errors, often causing delays, disputes, and incomplete asset documentation.

This study compares traditional surveying approaches with modern, geospatially enabled expropriation methods using a 10 km² case study in southern Saudi Arabia. The area was divided into two equal sub-areas: one surveyed using conventional field techniques and inventory committees, and the other using integrated GIS, satellite remote sensing, UAVs, LiDAR, Mobile Mapping Systems (MMS), and AI-assisted data analysis. Key performance indicators included number of properties surveyed, survey time, accuracy, asset inventory completeness, personnel requirements, and stakeholder transparency.

Geospatially enabled expropriation surveyed slightly more properties (430 vs. 420) with a 90% reduction in total survey time, fewer personnel (8 vs. 21), and higher boundary accuracy (±2–5 cm vs. ±20–30 cm). Asset inventories were nearly complete (99% vs. 85%), and office-based verification eliminated repeated site visits. The modern approach also enhanced transparency, defensible compensation calculations, and stakeholder trust, while minimizing environmental impacts from field operations.

Modern geospatial workflows outperform traditional methods in accuracy, efficiency, and transparency, providing an equitable and sustainable framework for urban land acquisition. Integrating these technologies supports SDG 10 (Reduced Inequalities) and SDG 16 (Peace, Justice, and Strong Institutions), promoting inclusive, lawful, and evidence-based expropriation practices.

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1. INTRODUCTION

Cities around the world are experiencing unprecedented growth, driven by population increases, economic expansion, and the rising demand for housing, infrastructure, and public services (Sun et al., 2020). While urban expansion can stimulate long-term economic growth and improve living standards for many, rapid and poorly planned expansion presents significant challenges for sustainable urban planning (Velasquez & Hester, 2013). In areas where growth outpaces the capacity of authorities to regulate, plan, and provide essential services, such expansion can lead to inefficient land use, encroachment on peri-urban agricultural lands or natural areas, and increased pressure on infrastructure such as water, electricity, and sewerage systems. These pressures threaten food security, disrupt local livelihoods, and degrade environmental quality, creating substantial social and economic challenges for communities in newly urbanized zones (Yigitcanlar & Teriman, 2015).

These pressures highlight a core dilemma: cities must accommodate rapid growth and develop modern infrastructure while preserving fairness (Grabowski et al., 2023), protecting existing land uses such as agriculture and natural areas (Albalawi, 2025), and ensuring equitable treatment of affected communities (Xu et al., 2025). Achieving these objectives aligns directly with Sustainable Development Goals (SDGs), particularly SDG 10 on Reduced Inequalities and SDG 16 on Peace, Justice, and Strong Institutions, which emphasize equitable access to resources, transparent governance, and inclusive decision-making processes. One of the pivotal processes in achieving this balance is expropriation, the legal acquisition of private land for public projects. Expropriation enables governments and urban planners to secure land for roads, utilities, schools, hospitals, parks, and other essential public services, allowing urban growth to follow planned layouts rather than haphazard development. By consolidating fragmented land parcels and coordinating land use, expropriation supports the creation of well-structured neighborhoods, efficient transportation networks, and accessible public amenities (Zuo et al., 2023). Yet despite these benefits, expropriation is often expensive and socially sensitive. Large-scale compensation can significantly impact public budgets, and when property valuations are unclear or perceived as unfair, the process may provoke disputes and erode community trust (Wang et al., 2016).

Historically, land expropriation has been implemented using traditional approaches that rely on field-based surveying, manual boundary identification, paper-based records, and extensive on-site engagement with landowners and inventory committees (Golob & Lisec, 2022). These methods, typically supported by conventional surveying instruments and administrative procedures, have formed the backbone of land administration systems for decades. While they offer legal legitimacy and direct community interaction, traditional expropriation workflows are often time-consuming, labor-intensive, and prone to inconsistencies between legal records and on-the-ground conditions, particularly in rapidly expanding urban environments. Such limitations can delay project delivery, complicate compensation assessments, and increase the likelihood of disputes.

In contrast, Recent advancements in geospatial technologies offer powerful tools to address these challenges. Geographic Information Systems (GIS) (Alqurashi & Kumar, 2013), satellite remote sensing (Mashala et al., 2023), drones (UAVs) (Yao et al., 2019), Mobile Mapping Systems (MMS), and AI-based geospatial analysis enable accurate spatial data collection, land-use monitoring, and real-time decision-making (Rezvani et al., 2023).

Specifically, satellite remote sensing combined with GIS has been widely applied to detect and analyze land use/land cover changes over time. Multi-spectral and multi-temporal satellite data facilitate quantification of land use changes (type, extent, timing), while GIS provides the scaffolding for analyzing, storing, and visualizing such data for planners and decision-makers (Santé-Riveira et al., 2008). These methods have been successfully employed in studies across the Middle East, Africa, and beyond to map urban sprawl, agricultural land loss, and irregular urban expansions (Myagmartseren et al., 2017). In particular, 3D modelling and 3D laser scanning not only provide centimeter- and millimeter-level precision in boundary delineation, building inventory, and property valuation, but also ensure equitable compensation, guaranteeing that every affected property owner receives their rightful share. These technologies, when integrated with GIS and dashboards, automate calculations, track changes over time, and provide transparent, defensible records for planners and stakeholders (Mokoena & Sebola, 2020).

Despite the growing adoption of geospatial technologies in land administration, there remains limited empirical comparison between traditional expropriation practices and modern, technology-driven approaches in terms of efficiency, accuracy, transparency, cost implications, and social outcomes. Addressing this gap, the aim of this paper is to systematically compare traditional and geospatially enabled land expropriation methods to evaluate their relative strengths, limitations, and overall effectiveness in supporting fair, transparent, and inclusive urban development aligned with SDG 10 and SDG 16. Using a case study of a proposed winter tourism center in southern Saudi Arabia, the paper examines how each approach performs with respect to boundary delineation, property valuation, compensation accuracy, implementation efficiency, and stakeholder engagement. Through this comparative analysis, the study seeks to identify best practices and provide evidence-based insights to support more informed decision-making in future expropriation projects

2. CASE STUDY

The study was conducted in Saudi Arabia, covering an area of 10 Km^2 characterized by varied terrain and diverse land uses, including residential, commercial, and agricultural parcels. The area comprises both developed infrastructure and informal settlements, requiring accurate cadastral mapping to support effective expropriation and urban planning.

3. METHODOLOGY

To evaluate and compare the effectiveness of traditional versus geospatially enabled expropriation approaches, the study area of 10 km^2 in southern Saudi Arabia was divided into two equal sub-areas, each covering approximately 5 km^2. One sub-area was designated for traditional expropriation**,** relying on conventional field surveying, on-site verification, and committee-based valuation. The other sub-area was assigned to a geospatially enabled workflow**,** utilizing integrated remote sensing, GIS, UAVs, MMS, and AI-assisted data analysis. This division allows a systematic comparison between the two approaches in terms of accuracy, efficiency, transparency, compensation reliability, and stakeholder engagement.

3.1. Preliminary Study and Ownership Gap Analysis

3.1.1. Traditional Approach:

For the traditional sub-area, property ownership and land use were identified using official land records and cadastral maps, complemented by on-site visits and interviews with property owners and inventory committees. Any missing or ambiguous ownership information was clarified through physical verification and discussions with municipal authorities.

3.1.2. Modern Approach:

For the geospatial sub-area, land ownership was first estimated using remote sensing, analyzing parcel size to distinguish between governmental and private land, a distinction crucial for compensation, since compensation is required only for privately owned land.

Remote sensing also provided information on parcel numbers, areas, built or vacant status, and number of floors, while Google Earth imagery was used to verify and label parcels. This assessment was complemented by a review of official property and ownership records from municipalities and Amana, and an ownership gap analysis was conducted to identify incomplete or misclassified records. By integrating remote sensing data with official records, an initial ownership baseline was established, quantifying parcels with identified versus uncertain ownership. This baseline guided targeted field surveys and detailed data collection, improving accuracy and reducing redundant site visits.

3.2. Surveying and Data Acquisition

3.2.1 Benchmark and Geodetic Network Establishment:

3.2.2. Traditional Approach:

Field teams conducted manual surveys, marking property boundaries on-site and measuring dimensions with total stations and GPS devices. Inventory and valuation committees visited each property, verifying land use, structure types, and asset presence. Data were recorded on paper forms, with calculations performed manually for compensation estimation.

3.2.3. Modern Approach:

A reference for the survey work was established through a geodetic network, including the installation of ground control points using best engineering standards. Six benchmark points were set across the study area to ensure measurement accuracy. These fixed, stable points, with precisely determined horizontal and vertical coordinates tied to the national geodetic reference system, provide a consistent spatial reference for positioning instruments and validating survey observations.

The geodetic network and benchmark establishment followed these technical stages:

- **Network Coverage Determination:** Points were distributed based on topography to ensure optimal network coverage.
- **Site Selection**: Locations were chosen for durability and long-term stability.
- **Triangulation & Verification:** Benchmarks were triangulated to check consistency, quantify errors, and validate positional accuracy for subsequent surveys.

Benchmarks are essential as permanent reference points for all surveying and construction activities. They enable accurate measurement of changes over time, support alignment and verification when buildings are removed or altered and ensure consistency across multiple survey campaigns. Benchmarks also serve as a foundation for topographic surveys, construction monitoring, and geospatial mapping, making all measurements traceable and reliable.

Data Acquisition: A combination of aerial and terrestrial survey methods was employed to capture detailed spatial information:

- **Unmanned Aerial Vehicle (UAV) Survey:** A DJI Matrice 350 RTK drone with a Zenmuse P1 camera and airborne LiDAR captured high-resolution imagery and dense 3D point clouds across the survey area. Flight paths ensured optimal image overlap, and Ground Control Points (GCPs) were established for accurate georeferencing and cross-zone consistency. RTK integration improved horizontal and vertical accuracy, while LiDAR provided detailed terrain, building, and vegetation measurements.

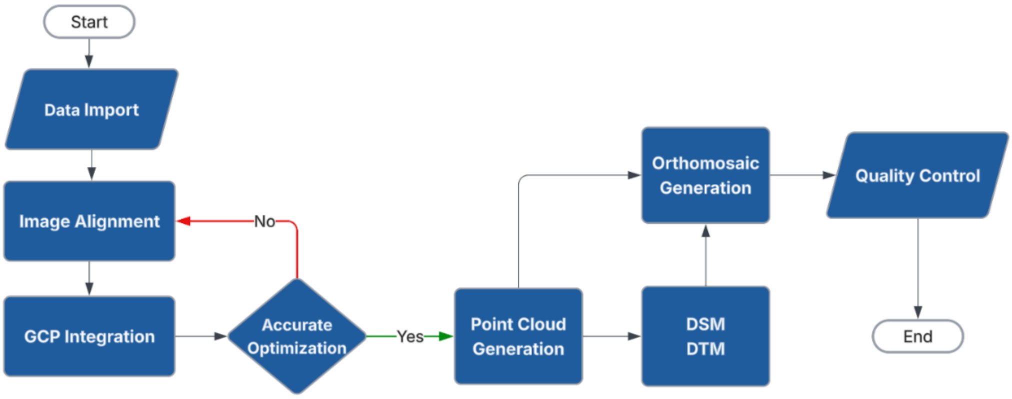
- **Mobile Mapping System (MMS):** High-resolution geospatial data were captured along road corridors using a vehicle-mounted MMS equipped with LiDAR sensors and panoramic cameras. Two GNSS base stations provided differential corrections for accurate trajectory post-processing. The vehicle maintained controlled speed to ensure proper point density, and raw GNSS/IMU data were processed in POSPac MMS. Trimble Business Centre (TBC) was used to generate georeferenced 3D point clouds, classify ground and non-ground features, and perform quality checks.

Figure 1. Drone outputs

Figure 2. Mobile mapping outputs

Data Processing: A structured workflow using Agisoft Metashape Professional and DJI Terra was implemented. Images were aligned, bundle adjustments applied, GCPs integrated, and dense point clouds generated. Digital Surface Models (DSM), Digital Terrain Models (DTM), orthophotos, and 3D building models were produced. Final feature extraction was performed in 3D CAD, digitizing buildings, roads, vegetation, and other infrastructure directly from point clouds, preserving spatial accuracy and geometry. All outputs were exported in standard geospatial formats for GIS, planning, and engineering applications.

Figure 3. Drone Data Processing Workflow



Outcome: This integrated MMS and UAV workflow produced high-accuracy, office-ready 3D models, comprehensive building and tree inventories, structural measurements, and digital maps suitable for planning, engineering studies, and land expropriation, eliminating the need for repeated field visits.

These outputs are critical for expropriation, as all property and structure details are readily available in 3D, eliminating the need to revisit the site to renegotiate with owners in case of compensation disputes. Noting that LiDAR outputs is the most accurate tool to convince people of the valuation, as it provides all the details about terrain, buildings, and other assets. Together, the aerial and terrestrial data enabled the creation of a comprehensive 3D model of the urban area to support precise mapping, valuation, and efficient expropriation processes.

3.3. Property Verification and Compensation

3.3.1. Traditional Approach:

Property committees physically inspected each parcel, confirming ownership, boundaries, and structural features. All findings were recorded manually, and valuation calculations were performed using committee-established pricing frameworks. Multiple visits were often required to resolve discrepancies.

3.3.2. Modern Approach:

With pre-collected geospatial data, there is no need for inventory and valuation committees to visit each property on-site with the owner to record assets manually. Detailed 3D models, digital maps, and comprehensive asset inventories allow all verification, measurement, and compliance checks to be performed directly in the office. LiDAR and MMS data capture every structural detail, asset, and natural inclusion, enabling accurate, transparent, and defensible compensation calculations without repeated field visits.

3.4. Data Management and GIS Integration

3.4.1. Traditional Approach:

Surveyed and committee-verified data were digitized manually and compiled in spreadsheets for valuation and reporting. Data integration was limited, and cross-referencing between property attributes, ownership, and assets required significant effort.

3.4.2. Modern Approach:

Unified Geodatabase (GDB): A geospatial database is the core component of GIS, integrating spatial data with descriptive attributes in a unified system to support accurate storage, analysis, and retrieval of land information. In this study, a unified geodatabase (GDB) was established to consolidate all project data, with each property assigned a unique identifier as the central reference. The GDB stores ownership details (owner name, ID number, and property ID) and all associated assets, organized by geometry: polygons (e.g., rooms and green areas) with area or volume, lines (e.g., walls and utility cables) with length and height, and points (e.g., trees) with height and quantity. Data quality and consistency were ensured through standardized schemas, naming conventions, topology rules, and controlled data entry using domains and subtypes. Implemented within a relational database environment, the GDB minimizes redundancy, supports temporal tracking of parcel changes, and enables transparent linkage between spatial boundaries, legal records, and valuation processes. Together, these capabilities provide a reliable foundation for efficient, transparent, and defensible land administration and expropriation.

Figure 4. GDB structure

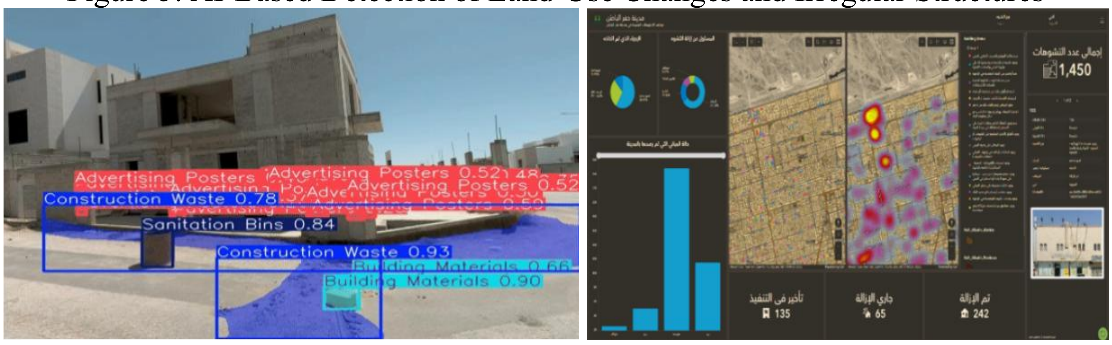
EMS Software, GIS, and Geodatabase Integration:
The Expropriation Management System (EMS), developed by Alqotr Company, was fully integrated with the project's GIS environment and a unified geodatabase (GDB) to ensure data

consistency, standardization, and traceability throughout the expropriation process. All users operated within the same GDB using standardized domains and subtypes, and asset naming conventions were defined from the outset to prevent duplication and inconsistencies. Buildings, walls, hedges, trees, and other property features were uniquely and consistently identified, ensuring that spatial and descriptive data were clearly defined and comparable across the project. After parcel contents were captured in the field and digitized in the GDB, all related ownership, asset, and valuation details were entered into the EMS, guaranteeing full alignment between field observations, spatial data, and system records. The EMS was further linked to the Customer Relationship Management (CRM) system, enabling daily cross-checking of submitted transactions and database entries to identify and correct discrepancies. Topology rules were applied to detect parcel overlaps and gaps, allowing early correction of spatial errors. While minor database updates may occur due to newly observed inclusions during field verification, standardizing asset names and prices prior to inventory and valuation was essential to maintain data integrity and ensure accurate, defensible compensation calculations.

AI-Based Feature Extraction and Object Detection: In the geospatial workflow, AI and deep learning models were applied to high-resolution UAV and satellite imagery to automatically detect and extract spatial features, including roads, buildings, and other assets. This automated process reduced manual digitization, improved completeness, and accuracy of the data, and enabled rapid integration of newly detected features into the unified geodatabase. As part of our methodology, AI-assisted feature extraction supported efficient property mapping, comprehensive asset inventories, and accurate, office-based verification for expropriation purposes.

Asset Valuation: Property values were also standardized. All estimators' input was consolidated, resulting in a unified pricing framework for each asset. This ensures that every property has a verified value recognized across the project, reducing errors and disputes.

Figure 5. AI-Based Detection of Land-Use Changes and Irregular Structures



4. RESULTS

The 10 km² study area was divided into two equal sub-areas (5 km² each) to compare traditional vs. geospatially enabled expropriation methods. Key performance indicators (KPIs) were collected, including Number of properties surveyed, Surveying and validation time, Human resources required, Accuracy and error rates, Number of repeat visits / verifications, Completeness of asset inventory, Cost estimation reliability.

The results are summarized in the tables below.

Table 1. Comparative Results Table

Criteria	Traditional Surveying	Modern Geospatial Surveying	Notes / Observations
Area covered	5 km²	5 km²	Same study area for fair comparison
Number of properties surveyed	420	430	Modern survey allowed slightly more due to better detection of small parcels
Average time per property	3–4 hours	15–20 minutes	Traditional methods required on-site visits and committee validation
Total survey time	~1,600 hours	~145 hours	Modern approach drastically reduces time
Number of employees required	15 field surveyors + 6 committees	6 GIS analysts + 2 survey operators	Modern approach reduces personnel significantly
Accuracy of boundary delineation	±20–30 cm	±2–5 cm	LiDAR and MMS provide centimeter-level precision
Measurement errors / discrepancies	12% of properties required repeat measurements	1–2% of properties flagged for minor review	Fewer errors in geospatial workflow
Number of field visits per property	2–3	0–1	Modern methods are mostly office-based
Asset inventory completeness	~85% of structural and natural assets recorded	99% of assets recorded	LiDAR + MMS captures details not visible from the ground
Cost estimation reliability	Medium	High	Standardized 3D data improves defensible valuations
Stakeholder engagement / transparency	Medium; reliant on committee explanations	High; 3D models and visualizations enhance clarity	Reduces disputes and increases trust

Environmental impact	Higher (multiple site visits, transport)	Lower	Modern approach reduces vehicle trips and site disturbances

The comparative analysis of traditional and geospatially enabled expropriation methods reveals substantial differences in efficiency, accuracy, and overall effectiveness. In the traditional sub-area, 420 properties were surveyed using field visits, paper-based records, and committee verification, requiring approximately 1,600 hours of work by 15 field surveyors and 6 valuation committees. Measurement discrepancies affected nearly 12% of properties, and multiple site visits were often necessary to resolve boundary conflicts and record all structural and natural assets, resulting in incomplete inventory (~85% of assets recorded) and moderate reliability in cost estimation. In contrast, the geospatial workflow allowed 430 properties to be surveyed with significantly higher precision, reducing survey time to approximately 145 hours and requiring only 6 GIS analysts and 2 survey operators. Detailed 3D models generated from LiDAR, UAV imagery, and Mobile Mapping Systems enabled complete asset documentation, accurate boundary delineation (±2–5 cm), and defensible compensation calculations, all performed directly in the office without repeated site visits. The modern approach also enhanced transparency and stakeholder confidence, minimizing disputes and providing standardized, verifiable data for planners. Overall, the results highlight that geospatially enabled expropriation not only improves operational efficiency but also ensures more accurate, equitable, and transparent land acquisition compared to traditional surveying methods.

5. DISCUSSION

The results of this study clearly demonstrate the significant advantages of geospatially enabled expropriation over traditional surveying methods in terms of accuracy, efficiency, and transparency. Traditional approaches, while legally recognized and widely used, proved to be labor-intensive, time-consuming, and prone to errors. Surveying 420 properties required multiple field visits, extensive manpower, and manual asset documentation, yet still resulted in incomplete inventories and a notable percentage of boundary discrepancies. These limitations not only delayed project timelines but also increased the potential for disputes over property valuation and compensation, highlighting the social and administrative challenges inherent in conventional expropriation processes.

In contrast, the modern geospatial approach delivered superior performance across nearly all measured criteria. By integrating remote sensing, GIS analysis, UAV surveys, LiDAR, and Mobile Mapping Systems, the study achieved high-precision property mapping, comprehensive 3D asset inventories, and defensible compensation calculations. Survey time was reduced by over 90%, and the requirement for large field teams and committee site visits was eliminated. These improvements translate into substantial cost savings, both in terms of personnel and operational logistics. Importantly, the office-based verification process allowed planners and committees to perform assessments efficiently while maintaining full compliance with legal and regulatory requirements.

Beyond operational efficiency, the modern approach enhances transparency, fairness, and inclusivity, which are central to sustainable urban land acquisition. Detailed 3D models and standardized valuation frameworks provide clear and verifiable records of property boundaries and assets, reducing subjective interpretations that often cause disputes in traditional methods. This evidence-based process fosters trust among property owners and stakeholders, supporting socially just expropriation practices. Furthermore, the high-resolution geospatial data enables ongoing monitoring and reassessment, allowing authorities to respond proactively to changes in land use, urban expansion, or asset modifications.

However, the adoption of geospatial techniques also entails initial investments in hardware, software, and training, which may present challenges for smaller municipalities or regions with limited resources. Nevertheless, for large-scale projects involving numerous properties and high compensation budgets, the long-term benefits—improved accuracy, reduced disputes, faster execution, and enhanced transparency—clearly outweigh these upfront costs.

Overall, this study confirms that while traditional surveying techniques remain viable for small-scale or low-complexity projects, geospatially enabled expropriation provides a more effective, accurate, and equitable framework for contemporary urban development. The findings support wider adoption of modern methods in large-scale land acquisition projects and highlight the potential for integrating technology to promote transparent, lawful, and inclusive urban planning practices.

6. CONCLUSION AND RECOMMENDATIONS

This study systematically compared traditional and geospatially enabled land expropriation methods in a 10 km^2 urban area in southern Saudi Arabia. The findings demonstrate that while traditional surveying remains legally valid and provides direct engagement with property owners, it is time-consuming, labor-intensive, and prone to errors, often requiring multiple site visits and extensive personnel. In contrast, modern geospatial approaches, integrating GIS, remote sensing, UAV surveys, LiDAR, and Mobile Mapping Systems, significantly improve accuracy, efficiency, and transparency. The geospatial workflow enabled precise boundary delineation, comprehensive 3D asset inventories, defensible compensation calculations, and office-based verification without repeated field visits.

The comparative analysis highlights that the modern approach not only reduces operational time by over 90% and personnel requirements but also enhances stakeholder confidence, social fairness, and compliance with legal frameworks. These outcomes directly contribute to achieving Sustainable Development Goals (SDG 10 and SDG 16), promoting equitable treatment of property owners, transparent governance, and inclusive land acquisition practices.

Overall, geospatially enabled expropriation proves to be a more effective, equitable, and sustainable approach for contemporary urban development compared to conventional methods.

Based on the findings of this study, the following recommendations are proposed for practitioners, policymakers, and urban planners:

1. **Adopt Geospatial Workflows for Large-Scale Projects:** Urban expropriation projects involving numerous properties should leverage GIS, UAV, LiDAR, and MMS technologies to improve accuracy, reduce survey time, and enhance transparency.
2. **Integrate Office-Based Verification Systems:** Detailed 3D models and digital asset inventories should be used to minimize the need for repeated field visits, reduce personnel costs, and ensure consistent and defensible compensation calculations.
3. **Standardized Data Management and Valuation Practices:** Creating unified geodatabases and standardized valuation frameworks ensures all property, asset, and structural data are traceable, consistent, and transparent, reducing disputes and enhancing stakeholder trust.
4. **Train Surveyors and Planners in Geospatial Techniques:** Investment in training for GIS, UAV operations, and LiDAR interpretation is essential to maximize the effectiveness of modern expropriation methods, particularly in regions transitioning from traditional approaches.
5. **Encourage Policy and Legal Support:** Governments should update expropriation regulations to explicitly recognize geospatial methods for property valuation and verification, ensuring legal compliance while promoting efficiency and fairness.

By systematically integrating geospatial technologies into land expropriation processes, urban authorities can achieve faster, more accurate, and socially equitable land acquisition, supporting sustainable urban growth while minimizing disputes and fostering trust among communities. This study provides a practical framework for evidence-based, transparent, and inclusive expropriation, applicable in both rapidly urbanizing regions and complex development projects worldwide.

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